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## THE RELATIVE APPLICABILITY OF CURRENT METHODS FOR THE DETERMINATION OF PUTRESCIBIL- ITY IN SEWAGE EFFLUENTS.

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LESS attention was formerly paid to the question of the putrescibility of sewage effluents than is the case at the present time. For the most part the purification processes then embraced either broad irrigation fields and intermittent sand filtration, which normally yield effluents of a high degree of purity, or chemical precipitations which remove only about one-half of the total organic matter. To-day there are many sewage problems in which purification requires to be carried apparently only to the extent of obtaining a non-putrescible effluent. For this purpose coarse-grain filters have a wide field of usefulness, and they also are a factor to be considered as an intermediate treatment in those sections where porous, sandy soil is not available naturally, and where thorough purification is needed.

Contact filters, or sprinkling filters of broken stone, do not, of course, effect as high a degree of purification at their best as do filters of fine-grain material, and when unskilfully operated may yield effluents containing sufficient unstable organic matter to render them putrescible. To obtain the most satisfactory results from such processes, frequent data are required regarding the putrescibility of the effluent. The great need, therefore, as is universally recognized, is for a test, whereby a determination of the character of the effluent, so far as relates to its putrescibility, may be speedily made, and thus enable the results to serve as a direct guide in operating the plant.

The putrescibility tests now in general use, from a practical standpoint, possess a common weakness in that nearly all, if indeed not all, are based upon a method whereby the samples of the effluent require incubation for several days before the result can be definitely known. So far as they are of assistance to the operators of

sewage works, the results of such tests are of value only as matters of record, to serve as a general guide in future operating procedure.

Numerous attempts have been made to fix certain arbitrary standards of purity of sewage effluents by prescribing that an effluent shall not contain more than so much organic nitrogen, or oxygen absorbed, thus (the data expressed in parts per million)—the Rivers Pollution Commission require an effluent to be below organic carbon 20, organic nitrogen 3; Thames Conservancy, organic carbon 30, organic nitrogen 11; Derbyshire County Council, albuminoid ammonia 1, oxygen absorbed 10 (4 hours' test); Ribble Board, albuminoid ammonia 1, oxygen absorbed 20 (4 hours' test); Mersey and Irwell, albuminoid ammonia 1.4, oxygen consumed 14.<sup>3</sup> At this time, however, there is an almost unanimous feeling against even the limited applicability of such standards. Albuminoid ammonia, organic nitrogen, and oxygen consumed indicate, not the exact proportion of putrescible matter in a sample, but rather, generally speaking, only a component part of these substances. Nitrogen, as determined by these tests, may be derived both from stable and unstable matters; organic carbon, as indicated by the oxygen consumed tests, may be represented not only by putrescible carbonaceous organic matter, but also by certain non putrescible substances requiring oxygen for their oxidation.

The putrescibility of a sewage effluent, as is quite generally recognized at this time, is intimately related to its composition with respect to its relative content of stable and unstable organic matter, readily oxidizable mineral substances, and the relative abundance of available oxygen present. For this reason it is certain that the mere knowledge of the amounts of putrescible organic matter present in a sample would be insufficient evidence upon which to base an opinion of the putrescibility of the sample. A knowledge of the amount of available oxygen present to counteract the putrescible tendencies of the sample is required. With a fairly accurate knowledge of the oxygen consumed by, and the oxygen available in, a sample, it is probable that in some cases at least it may be possible to fix arbitrary standards of purity of sewage effluents, so far as their putrescibility is concerned.

## INCUBATOR TESTS FOR THE DETERMINATION OF PUTRESCIBILITY.

*Brief historical résumé.*—The first recorded test for the character of sewage polluted water, so far as we are aware, was proposed in 1870 by Heisch,<sup>1</sup> who noted the fouling and growths produced when the sample, mixed with cane sugar, was exposed to sunlight. In 1884, Dupré<sup>2</sup> stated that when sewage polluted water was kept for 10 days out of contact with the air, a more or less complete absorption of the dissolved oxygen would take place, and that by a determination of the dissolved oxygen before and after incubation, an idea might be obtained regarding the amount of organic matter present. This process, as pointed out by Rideal,<sup>3</sup> aimed at determining the number of organisms present in the sample, rather than the amount of putrescible compounds contained therein.

Scudder,<sup>4</sup> chemist to the Mersey and Irwell Joint Committee, introduced in 1895 the incubator test, which, subject to a number of modifications, is in more or less general use at the present time. At the inception of this test, the procedure simply consisted in completely filling a bottle with the sample, stoppering tightly, and incubating for a few days at summer temperature. Later<sup>5</sup> Scudder refined the method by including in the technique the determination of the oxygen absorbed in cold acid permanganate in three minutes, before and after an incubation period of from five to six days at 75° F. This method was also used by Clowes<sup>6</sup> in the London experiments, and by Fowler<sup>7</sup> at Manchester. In the early Manchester experiments<sup>8</sup> this test was modified by the use of a period of incubation of from six to seven days at 80° F. Scudder<sup>9</sup> later included the determination of dissolved oxygen and nitrates, before and after incubation, since he found that effluents which did not show an increase in the amount of oxygen absorbed from permanganate would also contain after incubation residual amounts of dissolved oxygen and nitrates.

Ross<sup>10</sup> incubates at 80° F. for seven days, and further estimates the degree of putrescibility of the samples by determining the oxygen absorbed from permanganate in 15 minutes and four hours, respectively, at a temperature of 80° F. This method is also used by Wilkinson,<sup>11</sup> at the Oldham Sewage Works. Stoddart's<sup>12</sup> modification of the incubator test aimed to place the determination of the odor of putrescible samples upon a more severe basis, by making a simple quantitative test for hydrogen sulphide. Clark<sup>13</sup> incubates the samples at 80° F. for two to five days, and determines the oxygen consumed from acid permanganate during a two-minute boiling period, before and after incubation.

Attempts have been made in a number of instances to place the incubator test on a more practical basis, by imitating in the laboratory conditions such as obtain when the effluent is discharged into the watercourse. This was effected by diluting the sample with varying volumes of river water, corresponding to the dilution obtainable in practice, following which the sample was incubated at summer temperature for a number of days. Thus Adeney<sup>14</sup> suggests the dilution of the sample with river water before incubation. At Manchester,<sup>15</sup> it has been the practice for some time to incubate mixtures of the effluents and canal water. Clark<sup>16</sup> mixes equal volumes of effluent with tap water, and determines the amount of dissolved oxygen before and after incubation for five days at 80° F. In conjunction with this test he uses the two-minute oxygen consumed test already referred to, together with determinations of the amount of nitrites and nitrates present before and after incubation. Dunbar and Thumm<sup>17</sup> incubate the sample for one week in closed flasks at 68° F., note the formation of odors, and determine the presence of hydrogen sulphide with lead acetate paper.

The above is a necessarily somewhat incomplete digest of published literature bearing upon the incubator test for the determination of putrescibility. As is generally recognized, all of these tests, while yielding results of definite value, fall short of the most practical requirements, since the results obtained by these methods are not immediately available for the guidance of the sewage works operator.

*Results of the studies at Columbus on the incubator test.*— In a critical study of the incubator test and its various modifications at the Columbus Sewage Testing Station, we first turned our attention to a means of reducing the period of incubation. By adopting a temperature of 37° C., we were able in a majority of cases to obtain the same results as when, at lower temperatures, periods of incubation of several days were employed. Many determinations indicated that if odors did not develop after 24 hours at 37° C., they would also not be apparent after five days at 27° C. The relation between the period and the temperature of incubation in effecting putrefactive changes is clearly shown in the following table:

TABLE 1.  
EFFECT OF TEMPERATURE AND PERIOD OF INCUBATION ON THE RAPIDITY OF THE DEVELOPMENT OF PUTRESCENCE IN SEWAGE EFFLUENTS.

Character of Device	Coarse-Grain Filter		High Rate Sand Filter	
	27	37	27	37
Temperature of incubation, deg. C. ....	27	37	27	37
Period of incubation, days .....	5	1	5	1
Number of samples which gave positive results .....	117	108*	21	18*
Per cent which positive results obtained at 37° C. were of those obtained at 27° C. ....	92		86	

\*The balance of the samples incubated at 37° C. gave positive results at the end of 48 hours.

Our studies of the incubator test at Columbus, as outlined above, have shown that the period of incubation may be advisedly reduced to 24 hours, provided a temperature of incubation of 37° C. (98.5° F.) be used, since about 90 per cent of the samples incubated at 48 hours at this temperature developed odors of putrefaction in 24 hours.

#### SPECIAL CHEMICAL TESTS FOR DETERMINING THE PRESENCE OF PUTRESCIBLE COMPOUNDS IN SEWAGE EFFLUENTS.

Attempts have been made to determine by direct chemical tests the putrescibility of sewage effluents. Spitta<sup>18</sup> suggests that by adding to the sample enough methylene blue to impart a faint color, putrescible samples will quickly and completely discharge the blue color when incubated for a few hours at a temperature of 72° to 79° F. Fowler<sup>19</sup> has suggested that this test has quantitative possibilities which have yet to be worked out.

In the Columbus studies, consideration was given to this test, as well as to others, whereby the presence of albuminous and proteid

matters might be directly determined. From a study of the methylene blue test, we have found that oftentimes there would be present substances other than putrescible organic matters, such as sulphide of iron and hydrogen sulphide, which would immediately discharge the blue color, before the putrescible matters were able to act.

The other tests studied in this connection included the biuret reaction<sup>20</sup> and the use of Millon's reagent,<sup>21</sup> whereby it was thought that the presence of undecomposed albuminous substances could be detected. After an extended trial it was found that these tests did not distinguish between putrescible and non-putrescible substances; chiefly, it is thought, because putrescible substances are not confined wholly to the albuminoid class.

In addition to these studies, attempts were made to determine the putrescibility of an effluent by measuring its propensity to absorb oxygen from chemical oxidizing agents. First among these, iodine and hydrogen peroxide were studied. While it is true that, in connection with the use of all chemical oxidizing agents, certain complications arise in the presence of inorganic reducing agents, iodine and hydrogen peroxide are reagents of such high sensibility, that there are many inherent practical difficulties encountered in their use, which bar them from serious consideration among tests for determining the propensity of the effluent to consume oxygen.

In the further work at Columbus, a method was sought for the determination of putrescibility, which would correlate the results of the regular chemical analysis and the putrescible properties of the effluent. The direction in which the solution of the question seemed to lie, as has been previously noted, was in the balance between the oxygen available to offset the putrefactive tendencies of the effluent, and the actual amount of oxygen consumed in effecting this result. It was considered that in a certain degree the amount of oxygen consumed could be referred to the regular "oxygen consumed" values from permanganate. Where the amount of available oxygen exceeded the amount of oxygen consumed, it appeared certain that such conditions favored the ultimate complete oxidation of the unstable matters without accompanying nuisances.

In order to obtain information on the relation between the results obtained by the various "oxygen consumed" tests, coincident

with the putrescibility of the sample as referred to the odor developed after incubation in a tightly stoppered bottle for 24 hours at 37° C., the several tests were applied to a large number of samples collected from various sources. The modifications in the oxygen consumed test which were used in this comparative study were as follows: (a) The instantaneous oxidation by permanganate in a cold acid solution;<sup>22</sup> (b) Oxidation by permanganate during a three-minute period of digestion in a cold acid solution;<sup>23</sup> (c) Ditto in a 15-minute period of digestion;<sup>24</sup> (d) Oxidation by permanganate during a period of digestion of 30 minutes in boiling water;<sup>25</sup> (e) Oxidation by permanganate at boiling temperature during a five-minute period.<sup>26</sup> Duplicate samples were also incubated, as above described, and their putrescibility determined by the odor test. The results, which are given in the following table, indicate that the relative amounts of "oxygen consumed," as shown by the modified methods according to which the more rapid determinations are made, are naturally greater in the putrescible than in the non-putrescible samples. The more prolonged and higher temperature tests simply serve to emphasize these differences.

TABLE 2.  
COMPARISON OF OXYGEN CONSUMED RESULTS OBTAINED BY DIFFERENT METHODS OF ANALYSIS IN  
PUTRESCIBLE AND NON-PUTRESCIBLE SAMPLES.

Method	Time of Contact (Minutes)	Tempera- ture, Deg. F.	Oxygen Consumed Parts per Million		Relation of Results by Other Methods to Those Obtained by the Boston Method	
			Putres- cible Samples <i>a</i>	Non- Putrescible Samples <i>b</i>		
					<i>a</i>	<i>b</i>
Immediate	1	80	3.5	1.5	0.17	0.21
English	3	80	4.2	1.4	0.20	0.20
English	15	80	9.7	2.5	0.46	0.35
Boston	5	Boiling	20.9	7.2	1.00	1.00
Palmer	30	"	44.7	12.0	2.13	1.67

#### RELATION OF THE COMPOSITION OF A SEWAGE EFFLUENT TO ITS STABILITY.

*Unstable organic and inorganic matter.* — Putrescibility may be due to the presence of complex bodies of either animal or vegetable origin, depending entirely upon the character of the raw sewage. The relative amounts of these two classes of organic matter are roughly indicated by the amounts of organic nitrogen, and "oxygen

consumed," respectively. Since the same amounts of nitrogen or oxygen consumed may be present in one case in a crude sewage, and in another in a stable effluent, it is clear, as pointed out by Dunbar and Thumm,<sup>27</sup> that it is the relative, and not the absolute, amount of organic matter in sewage before and after purification, that is to be taken as the criterion for the consideration of questions relating to putrescibility.

The breaking-down by hydrolysis of the complex, highly organized bodies containing sulphur gives rise to the formation of considerable amounts of sulphureted hydrogen. Sulphur in this form rarely occurs in sewage effluents, however, since the iron in the crude sewage, or in the filtering material, combines with the sulphureted hydrogen to a sulphide, which is ultimately oxidized to sulphate in effluents which are normally stable. In fact, the absence of sulphide of iron in the effluent<sup>28</sup> may be taken as an indication of the adequacy of the aeration facilities within the filter; and further, perhaps of more moment for the putrescibility question, sulphide of iron will not develop in an effluent when stored, provided the conversion to a stable form of the organic matter therein has been sufficiently completed in the filter. The putrefactive tendencies of a sewage effluent thus refer to unstable organic bodies which are generally found to be coincident with the presence, or the subsequent formation, of sulphide of iron.

#### THE AVAILABILITY OF OXYGEN OF DIFFERENT KINDS AS FOUND IN SEWAGE EFFLUENTS.

In the case of some of the rapid processes, a very considerable proportion of the purification effected by rapid filters of coarse material may be said to take place under anaerobic conditions, and through agencies in which oxygen is not directly concerned. But, as has already been mentioned, the great majority of causes underlying putrescible conditions in sewage effluents refer to a supply of oxygen within the filter insufficient to effect the changes which bring about stable conditions in the effluent.

*Availability of gaseous oxygen and oxygen combined with nitrogen.* — In a sewage effluent there are two sources of oxygen, which the studies of a number of workers besides ourselves have shown

to be available for the protection of the effluent against putrefaction. These are dissolved gaseous oxygen, and the oxygenated compounds of nitrogen, nitrogen pentoxide ( $N_2O_5$ ), and nitrogen trioxide ( $N_2O_3$ ), commonly spoken of as nitrate and nitrite oxygen, respectively. Rideal<sup>29</sup> says that the "available oxygen" is that present as nitrate and nitrite, and that the amount in a satisfactory effluent is quite sufficient to overcome putrefaction, without the aid of the dissolved oxygen in the stream into which the effluent is discharged. By adding certain amounts of sodium nitrate to clarified sewage, Adeney and Scott-Moncrief<sup>30</sup> take advantage of the availability of oxygen from that source. Sewage so treated, after retention in a tank for several hours, may be discharged therefrom in a stable condition. During the experiments at Manchester,<sup>31</sup> the effect of mixing a nitrated and a crude tank effluent was studied as a means of reducing the required acreage of the purification works. The result of these studies showed that, within certain limits, a considerable volume of crude tank effluent could be rendered stable in this manner. In experiments in which equal volumes of tap water and putrescible sewage effluent were kept at summer temperature for several days, Clark<sup>32</sup> showed a marked diminution in the initial amounts of dissolved oxygen and nitrate oxygen. In non-putrescible samples, treated similarly, no such pronounced reduction in the available oxygen took place, and an appreciable amount of residual oxygen was always noted. Fowler<sup>33</sup> also affirms that a well-nitrated effluent is protected against putrefactive tendencies. The well-known researches by Gayon and Dupetit<sup>34</sup> show that marked decomposition of unstable organic compounds is effected by the reduction of nitrates by bacteria. Similar observations have been made by numerous other observers.

*Availability of other sources of oxygen.* — There are a number of oxygenated compounds in sewage effluents, besides those already discussed, which require a passing comment regarding the availability of oxygen from such sources for overcoming putrescible conditions. Sulphates and oxide of iron are among those which particularly suggest themselves. The question arises, however, whether we are to regard oxygen, chemically combined in such stable atomic aggregations, as available under the reduction forces at work when

a but partially purified sewage undergoes putrefactive change. While the bacterial reduction of sulphate to sulphide, and of ferric oxide to its ferrous state, has been noted by other observers, the conditions were somewhat different from those encountered in studies relating to the putrescibility of sewage effluents. Clark<sup>41</sup> is of the opinion that sulphates in sewage will undergo a considerable decomposition under septic conditions, the extent of their reduction in a septic tank, in which a period of flow of about 24 hours was maintained, being shown as about 7 per cent. Fuller<sup>42</sup> has shown that in the sediment deposited from Ohio River water, prior to the process of the decomposition of the organic matter contained therein, it is probable that there took place a reduction of the oxygen present in the mineral compounds, such as sulphates and nitrates, and a reduction of ferric to ferrous iron.

During the studies on the putrescibility question made at the Columbus Sewage Testing Station, such question as these have been given a careful consideration. For the purpose of learning whether any considerable reduction of the sulphates, which the Columbus sewage normally contains, took place under the active reducing actions present in septic tanks, the influent and the effluent of two of the septic tanks in operation at the testing station were sampled at half-hourly and hourly intervals, respectively, for a period of one week during the month of May. At the end of that time the various portions were mixed and examined for sulphates. The results of this experiment are presented in Table 3 and show conclusively that sulphates ( $\text{SO}_4$ ), present in the applied sewage to the extent of 200 parts per million, did not suffer any appreciable reduction when exposed for 16 and 24 hours, respectively, to the reducing action incidental to the septic process under local conditions.

While, as Fuller<sup>42</sup> has pointed out, it is probable that oxide of iron will yield up its oxygen under the conditions stated, its reduction implies highly putrescent conditions such as would not obtain in an effluent of ultimate stability. It seems clear, therefore, that in overcoming putrescible tendencies in a sewage effluent, only gaseous oxygen and oxygen combined with nitrogen can be considered as available sources of oxygen in effecting bacterial oxidation to a condition of ultimate stability. Further, as already noted, fixed

TABLE 3.  
TABLE SHOWING THE EFFECT OF SEPTIC ACTION UPON THE SULPHATES IN CRUDE SEWAGE.

DEVICE	PARTS PER MILLION $\text{SO}_4$		
	1	2	Average
Crude sewage.....	208	208	208
16 Hour septic tank .....	203	205	204
24 Hour septic tank .....	201	...	201

NOTE. — Method of determining sulphates: In boiling acidified solution precipitated sulphate with barium chloride. Filtered through tarred Gooch crucible, ignited, and weighed.

standards referring to certain maximum permissible amounts of organic nitrogen, albuminoid ammonia, or oxygen consumed, cannot be taken as indications of such conditions.

#### METHODS FOR THE DETERMINATION OF PUTRESCIBILITY BASED UPON CURRENT CHEMICAL DATA.

With a thorough knowledge of all the factors associated with the causation of putrescibility, it would seem that the results of chemical analysis which, up to the present time and now, represent the extent to which the differentiation of the several constituents in the effluent may be carried, should furnish also information as to the putrescible properties of a given sample. Considering introspectively the nature of the conditions under which putrescibility takes place, and studying carefully also the factors which are instrumental in preventing the putrescent reorganization of unstable organic matter, we are forced, like others, to the conclusion that the putrescibility factor narrows itself down to the amount of oxygen available for aerobic decomposition.

The oxygen consumed results, as obtained by the standard five-minute boiling method,<sup>26</sup> measure fairly accurately the amount of oxygen consumed in the oxidation of the unstable matter present in the sample. Since the reactions, as a result of which the ultimate reorganization of crude organic matter takes place under aerobic conditions, are subject to the uncertainties incidental to the action of bacteria, it would seem inadmissible to infer that the amount of oxygen necessary to complete the oxidation of the putrescible organic constituents of the sewage effluent, as indicated by chemical oxidizing agents, would be the same as that necessary for the accomplishment of the oxidation of such matter by bacteria. It seems certain,

therefore, that the most probable direction in which would lie the satisfactory interpretation of "oxygen consumed" results, with respect to the premises of putrescibility, refers to the establishment of a relation between the oxygen absorbed from permanganate and its bacterial equivalent.

The oxygen available in a sewage effluent to offset its putrescible tendencies, as has already been pointed out, is the amount of oxygen present in the sample in a dissolved gaseous state and that combined with nitrogen in the form of nitrate and nitrite. A measure of the putrescible tendencies of an effluent may be closely estimated from the amount of oxygen absorbed from permanganate during a three-minute digestion of the sample in a cold acid solution. This feature has been put forward many times before by other workers, and it is merely our desire at this time to record the fact that our work confirms the stability of their conclusions. We desire to emphasize the fact, however, that in some instances this may not be absolutely true, but for the majority of cases we believe that such is the case. Further, the results of our studies lead us to feel that under average conditions there is an intimate relationship existing between the three-minute cold test,<sup>23</sup> and the five-minute boil test.<sup>26</sup> In Table 2 it was clearly shown that the former value was one-fifth of the latter.

It is the available oxygen contained in the effluent in the form of dissolved oxygen and oxygen combined as nitrates and nitrites, which may be said to serve as a protecting agent in preventing the establishment of putrescent conditions. Our studies indicate that the existing relation between the oxygen absorbed from permanganate in cold acid solutions in a period of three minutes — or a similar "oxygen consumed" value obtained by dividing the result of the five-minute boil test by five — and the available oxygen which the effluent contains, may furnish a satisfactory means whereby the oxygen required and available, respectively, may be placed upon a comparable basis.

RELATIVE AVAILABILITY OF DISSOLVED OXYGEN AND OXYGEN  
COMBINED WITH NITROGEN IN THE NEUTRALIZATION OF  
PUTRESCIBLE TENDENCIES IN SEWAGE EFFLUENTS.

In our studies of the putrescible qualities of sewage effluents, and those factors which serve to prevent putrescence, certain facts

were brought out with considerable distinctness. We desired to learn if a fairly definite relationship existed between the consumed and the available oxygen, as indicated by the results obtained through the medium of certain "oxygen consumed" methods, and by the amounts of oxygen contained in the effluent which could be properly considered as available for the prevention of putrescent conditions. A large number of tests were made to determine the "oxygen consumed" by the three-minute cold and the five-minute boil methods, respectively, together with the amount of available oxygen contained in the effluents of the various devices under study at the Sewage Testing Station. The results of these studies brought out the fact that there does exist a more or less definite relation between the amount of oxygen consumed, as determined by chemical tests, the dissolved oxygen, and that available through bacterial action from the nitrates and nitrites which the effluent contains. In the course of these studies, carried on side by side with incubator tests, we were inclined to believe that in cases where the oxygen consumed, as shown by the chemical tests described above, was, before incubation, less than the amount of available oxygen computed from the amount of dissolved oxygen and from those amounts available from nitrites and nitrates, respectively, such an effluent would not putrefy on incubation; and such, in the majority of cases, has turned out to be the case.

To place such deductions as these on a stable basis, we realize that a definite statement is required as to the respective coefficient of availability of oxygen dissolved in the effluent in the free gaseous form, and that present in combination with nitrogen in the form of nitrate and nitrite. In this connection we have already noted that sprinkling filters yield at times a putrescible effluent which, while not well nitrified, may still contain amounts of dissolved oxygen sufficiently great to prevent the establishment of putrescent conditions, if the availability coefficient of dissolved oxygen were unity. That the reverse has been found to obtain in many instances is shown by the results presented in the next table. These data are representative of many similar cases, where, under the same conditions with respect to the content of the effluent in organic nitrogen and oxygen consumed, the effluent was clearly putrescent after in-

cubation. In these cases, while the nitrate and nitrite oxygen were present in low quantity, the amount of gaseous oxygen dissolved in the effluent was high. Dissolved oxygen plays such an important part in the disposal of sewage in flowing streams by preventing putrescent conditions therein that such results as these, in the absence of more extended evidence, are clearly to be regarded as abnormal. It is therefore the desire of the writers merely to suggest the possibility that such conditions may arise in the case of sprinkling filter effluents with the thought that perhaps further investigation under a different set of conditions may satisfactorily explain them.

TABLE 5.  
AVAILABILITY OF DISSOLVED OXYGEN.

PARTS PER MILLION					PUTRESCIBILITY TEST BY ODOR AFTER INCUBA- TION	OXYGEN CONSUMED (5 MIN. BOIL÷5) WAS TO OXYGEN AVAILABLE FROM:		
Oxygen Consumed			Available Oxygen			Dis- solved	Combined with Nitrogen	Total
5 Min. Boil÷5	3 Min Cold	Dissolved	Combined with Nitrogen	Total				
7.6	6.5	7.1	4.1	11.2	+	1.0.93	1.0.54	1.1.47
6.6	6.3	3.5	5.2	8.7	+	0.53	0.79	1.32
6.0	6.0	5.2	2.4	7.6	+	0.87	0.40	1.27
5.6	5.8	5.7	1.6	7.3	+	1.02	0.29	1.31
6.0	5.5	7.3	1.5	8.8	+	1.22	0.25	1.47
5.2	5.7	6.6	3.1	9.7	+	1.27	0.60	1.87
5.8	5.5	8.3	2.0	10.3	+	1.43	0.35	1.78
5.4	6.0	8.4	2.5	10.9	+	1.56	0.46	2.02
5.0	5.5	8.3	2.7	11.0	?	1.66	0.54	2.20

In the following table the amount of oxygen consumed is represented both by the results of the five-minute boil method, and the three-minute cold method. In the computations of the amount of consumed oxygen the corrected results of the five-minute boil method are used, for the reason that it appears to us a somewhat more reliable method for indirectly measuring the amount of oxygen consumed by the easily oxidizable matter in a sewage effluent. The three-minute test, to our thought, possesses a considerable weakness in that it emphasizes disproportionately the value of inorganic compounds of ready oxidizability. Further, the technique entailed by this method is somewhat more delicate than that employed in the five-minute boil method, and subject to somewhat greater possibilities of inaccuracy.

TABLE 6.

SELECTED RESULTS OF PUTRESCIBILITY TESTS ILLUSTRATIVE OF THE VARIABLE VALUE OF THE SEVERAL AVAILABLE FORMS OF OXYGEN.

PARTS PER MILLION					Putresci- bility Test by Odor after In- cubation	OXYGEN CONSUMED (5 MIN. BOIL + 5) WAS TO OXYGEN AVAILABLE FROM:			Putrescent Condi- tions on Incubation Probably Due to the Inactivity of:
Oxygen Consumed		Available Oxygen				Dis- solved	Combined with Nitrogen	Total	
5 Min. Boil	3 Min. Cold	Dis- solved	Combined with Nitrogen	Total					
3.2	2.8	1.7	1.0	2.7	+	1:0.53	1:0.31	1:0.84	*  *  *  *  §  §*
4.2	3.9	7.4	7.0	14.4	?	1.76	1.67	3.43	
5.6	4.6	0.0	5.1	5.1	+	0.00	0.91	0.91	
7.2	9.2	6.2	0.9	7.1	+	0.86	0.12	0.98	
2.8	7.7	3.6	5.1	8.7	O	1.29	1.82	3.11	
3.2	4.5	0.1	2.5	2.6	+	0.03	0.78	0.81	
3.2	3.4	0.0	3.8	3.8	?	0.00	1.19	1.19	
5.0	3.8	7.7	2.7	10.4	?	1.54	0.54	2.08	
4.6	13.9	2.1	2.9	5.0	?	0.46	0.63	1.09	
4.2	6.8	1.6	4.9	6.5	?	0.38	1.17	1.55	
3.8	3.2	8.4	2.3	10.7	+	2.21	0.61	2.82	
5.0	5.3	0.2	3.5	3.7	+	0.04	0.70	0.74	
9.8	3.7	6.4	8.0	14.4	+	0.65	0.82	1.47	
4.0	3.4	7.9	6.8	14.7	?	1.97	1.70	3.67	
5.8	10.6	4.3	1.7	6.0	+	0.74	0.29	1.03	
3.6	4.0	0.1	3.0	3.1	+	0.03	0.83	0.86	
7.2	8.8	5.3	5.5	10.8	+	0.74	0.76	1.50	
4.4	4.2	6.7	4.1	10.8	?	1.52	0.93	2.45	
3.6	3.5	1.1	4.7	5.8	O	0.31	1.30	1.61	
5.2	5.0	3.6	1.4	5.0	?	0.69	0.27	0.96	
3.2	3.4	6.8	7.6	14.4	?	2.13	2.37	4.50	
3.2	3.6	0.0	5.8	5.8	O	0.00	1.81	1.81	
4.8	4.2	4.7	5.6	10.3	+	0.98	1.17	2.15	
3.4	3.7	0.6	3.9	4.5	O	0.18	1.14	1.32	
2.2	2.8	0.1	2.1	2.2	?	0.05	0.95	1.00	
5.4	4.9	0.1	3.4	3.5	+	0.02	0.63	0.65	
5.4	6.3	6.3	2.5	8.8	O	1.17	0.46	1.63	
6.2	7.1	3.9	8.2	12.1	+	0.63	1.32	1.95	
5.0	5.0	5.7	4.9	10.6	+	1.14	0.98	2.02	
3.2	3.4	3.4	0.8	4.2	?	1.06	0.25	1.31	
4.2	3.6	2.5	3.2	5.7	O	0.60	0.76	1.35	
3.2	3.1	1.7	1.0	2.7	+	0.53	0.31	0.84	

NOTE. — + = Odor like H<sub>2</sub>S, strong and lasting. ? = Ditto, but very faint and immediately disappearing. O = No offensive odor. \* = Dissolved oxygen. § = Oxygen combined with N.

#### THE RAPID ESTIMATION OF THE PUTRESCIBILITY OF SEWAGE EFFLUENTS.

From a practical standpoint no information regarding the efficiency of a sewage filter is so promptly required as is knowledge of the putrescibility of the effluent. The methods in use at this time for the determination of this feature generally include a period of incubation of from five to seven or more days. There is an urgent need, however, as is recognized by all, of a method which will permit of at least an approximation of the putrescible character of the effluent of a filter, and which will yield information sufficiently accurate to make possible opportune changes in operating proced-

ures whereby the character of the effluent may be improved at once, instead of several days after it has commenced to deteriorate. In the light of present knowledge on the subject, it would be unreasonable to expect a method to be found for this purpose which would, at all times and under all conditions, yield an absolutely correct result; but the results of our studies lead us to conclude that an idea of the putrescible character of a sewage effluent, sufficiently accurate for all ordinary purposes, may be secured in the space of an hour, or so, as follows:

*Determination of putrescibility by computation from the chemical data.* — The analytical data required include the “oxygen consumed” by the five-minute boil method, the nitrogen as nitrite and nitrate, respectively, and the dissolved oxygen. The oxygen consumed is estimated by dividing the “oxygen consumed” by five. This factor represents the coefficient whereby the “oxygen consumed” result may be converted to its bacterial equivalent, or the value indicating the amount of consumed oxygen. The amount of available oxygen is determined by converting the nitrogen, as nitrite and nitrate, respectively, to oxygen, by multiplying the nitrogen value of these two constituents by the factors 1.71 and 2.86, respectively, representing the relative amounts of oxygen combined with nitrogen in these two forms. The sum of the oxygen available from these nitrogen compounds, together with a somewhat uncertain proportion of the dissolved oxygen, represents the real active agent in the prevention of putrescent conditions in a sewage effluent.

With the data above outlined at hand, we feel that it is admissible to interpret the putrescibility of an effluent in the following manner:

First, when the consumed oxygen value is equal to or in excess of the amount of dissolved oxygen in the effluent, and no nitrates or nitrites are contained therein, the sample will putrefy.

Second, when the consumed oxygen value is equal to or slightly less than the amount of oxygen contained in the effluent in the form of nitrates, nitrites, and dissolved oxygen, the sample may or may not putrefy.

Third, when the consumed oxygen value is less than the oxygen contained in the effluent in the form of nitrates and nitrites, under ordinary circumstances the sample will not putrefy.

Such are the relations which our results indicate as existing between the constituents of chemical analysis and putrescibility. While we have found that such deductions, as outlined above, admitted of quite extended application to conditions obtaining at Columbus, we do not wish to be misunderstood as contending that these provisional criteria of putrescibility will prove to be of general applicability, under the great variety of conditions encountered in the practical control of sewage works. We feel, however, that the knowledge gained in these studies possesses considerable suggestive value, which may possibly serve as a basis for future studies along similar lines.

The chemical tests involved in the rapid estimation of putrescibility, as outlined above, are such that the services of a competent analyst will be required in connection with the sewage works where such tests may prove to be applicable. In small works, where the expense of such a man might be considered as prohibitive, the incubator tests may be employed to afford the desired information. In this connection we desire to call attention to the feasibility of employing a period of incubation of 24-48 hours at 37° C., instead of the longer periods at lower temperature in more or less general use at the present time.

In conclusion the writers desire to acknowledge the courtesy of Mr. Julian Griggs, chief engineer of the Board of Public Service, in permitting the use of data embodied in this paper. They desire further to make acknowledgment of the suggestions and criticisms offered by Mr. George W. Fuller, who, as one of the consulting engineers to the city of Columbus on sewage disposal matters, has closely followed the work herein described from its conception.

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